TECHNICAL MEMORANDUM

South Sacramento County Agriculture and Habitat Lands Recycled Water, Groundwater Storage, and Conjunctive Use Program Water Storage Investment Program Application Surface Water Operations and Temperature Modeling

PREPARED FOR:	Sacramento Regional County Sanitation District RMC, a Woodard & Curran Company
PREPARED BY:	Robert Leaf/CH2M
CC:	Matt Franck/CH2M
DATE:	August 7, 2017

Introduction

Summary of the Program

This document describes the impacts and benefits to surface water, based on modeling analysis, to support a Water Storage Investment Program (WSIP) grant application for the proposed Program: South Sacramento County Agriculture and Habitat Lands Recycled Water, Groundwater Storage, and Conjunctive Use Program (Program). This conjunctive use program is designed to strike a balance between water resources sustainability, ecosystem enhancement, and agricultural sustainability in an increasingly urban environment, supporting Regional San's commitment to environmental stewardship for the Sacramento Region.

Summary of Key Findings

The modeling of surface water conditions presented in this document provides information for use in preparing an application for funding under the Water Storage Investment Program (CWC, 2016a). A companion document presents the modeling of groundwater conditions (see: *Integrated Groundwater and Surface Water Modeling Results Technical Memorandum,* Woodard & Curran, 2017).

The effects of the Program on surface water conditions are summarized in Figure 1. At the start of Program operations, wastewater recycling for groundwater recharge and associated Regional San discharge reductions are 50,000 acre-feet per year (AFY). The change in surface water is a reduction in the same amount, the highest over the life of the Program. After ten years of operations, streamflows into the Cosumnes and Sacramento River have increased due to higher groundwater levels. Additionally, groundwater extractions and associated reductions in surface water diversions are occurring in driest hydrologic conditions. After ten years, the change in surface water is a reduction of 24,980 AFY and in drought conditions 15,140 AFY. After ten years, the risk of impacts to upstream reservoirs such as Shasta Lake, and the risk of impacts to temperature conditions in the reaches downstream of those reservoirs, are reduced to negligible levels. After twenty years of operations, with increases in streamflows due to higher groundwater levels up to a maximum 34,880 AFY, the change in surface water is a reduction of 7,970 AFY and in drought conditions an increase of 720 AFY. After twenty years, the risk of impacts to Delta outflow and Delta exporters is reduced to negligible levels. After ten years and more so after twenty years of operations, there are months of the year where the net change in surface water in the Delta is an increase over Without Project conditions. With the Project, increases occur in all months of all year types in the Cosumnes River and Mokelumne River inflows into the Delta. After twenty years, increases in streamflows to the Cosumnes River and Mokelumne River amount to an increase of 33,130 AFY. More details are included in the following Assumptions and Results sections.

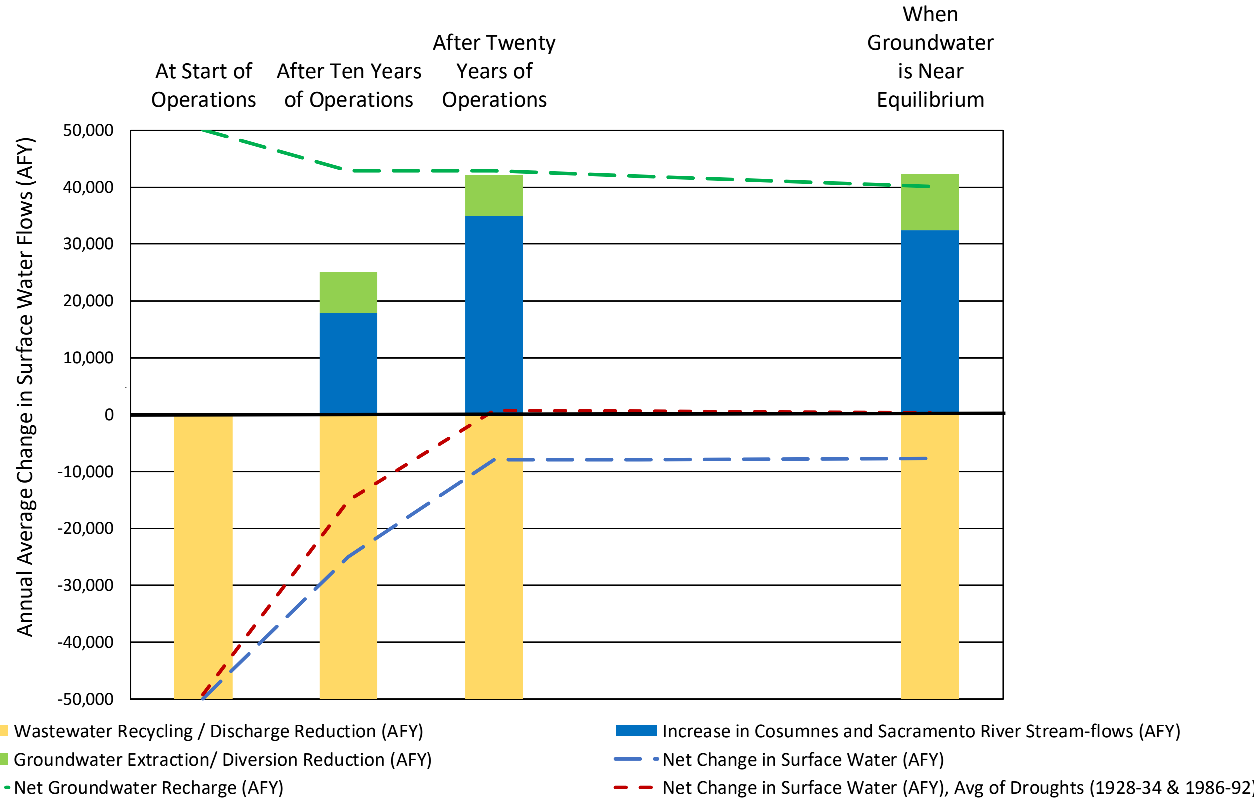

Figure 1. Change in Flows for Regional San Program Scenarios Evaluated (unless indicated in legend, values shown are annual averages over the 82 years of hydrologic record simulated with CalSim-II, values tabulated in Table 1)

Evaluating the Program for the WSIP Application

The WSIP has provided Quantification Regulations, hydrologic data and model products, and a Technical Reference document for applicants' use (CWC, 2016b and 2016c). An application for funding under the WSIP is required to follow the regulations, use the data and models provided, and adhere to the technical reference in preparing analysis of the Program. For surface water modeling and evaluation of the Program, the WSIP has provided hydrology data and CalSim-II models for projected climate conditions anticipated in the years 2030 and 2070.

Two surface water models were used for this evaluation: CalSim-II and HEC5Q. The CalSim-II model is used to simulate the hydrology of the Central Valley and the water operations of the CVP, SWP, and the Delta. The HEC5Q model is used to simulate water temperature conditions in the Sacramento River and the American River. A period analysis approach was used for this evaluation (see the Approach section).

For the purposes of the WSIP application, the Program is evaluated at four points in time over the life of the Program:

- At start of Program operations (anticipated to occur in the year 2023)
- After ten years of Program operations
- After twenty years of Program operations or at which point groundwater conditions are assumed to be near equilibrium[1]
- At fifty years of Program operations

It should be noted that the modeling assumes full Program build-out at the start of Program operations. It is expected that it will take in excess of ten years to achieve build-out, thus the "start of Program operations" and "after ten years of Program operations" are very conservative and impacts seen in these simulations would likely be smaller due to the time required to fully build-out the Program.

For the first three points in time (start of Program operations through twenty years of Program operations), the hydrology data and CalSim-II model used for the evaluation are based on the WSIP projected 2030 climate conditions. For the last point in time (fifty years of Program operations), the hydrology data and CalSim-II model used for the evaluation are based on the WSIP projected 2070 climate conditions. The range of potential effects of the Program between the third point (twenty years of Program operations) and the last point in time will show how the effects of the Program under equilibrium groundwater conditions vary with climate change between 2030 and 2070 climate conditions.

The four points in time over the life of the Program were selected to highlight different conditions in net groundwater recharge and net change in surface waters over the life of the Program and allow for the interpolation of Program benefits and impacts over the life of the Program as required by the WSIP regulations

At start of Program operations use of recycled water for groundwater recharge and resulting reduction of discharges into the Sacramento River has begun, however groundwater conditions

[1] Groundwater modeling using the SacIWRM did not reach an equilibrium within the 84-year simulation period, but did approach an equilibrium. "Near-equilibrium" is termed in this effort to be the condition where increases in storage are small in comparison to increases in streamflow and do not change significantly over time. In such a situation, streamflow increases are slightly less than the annual average amount recharged. This contrasts with initial years in the simulation where increases in storage are large in comparison to increases in streamflow and groundwater conditions are changing relatively quickly.

have not yet improved. With each year of Program operations, groundwater conditions improve over the previous year. After ten years of Program operations, with ten years of recharge, sufficient water is banked in the groundwater in the region to allow for groundwater extractions resulting in reduction of diversions from the Sacramento River. It is anticipated that water would only be extracted after it has been previously banked. As only 30% of recharged water is assumed available for extraction from a management perspective, after 10 years of recharge there could be expected to be 3 years of extractable water in the aquifer system. Even though groundwater conditions are not yet near-equilibrium, increased groundwater conditions result in a corresponding increase in streamflows in the Cosumnes River and Sacramento River. After twenty years of Program operations, with more years of recharge, and some extractions in Driest[2] years, sufficient net recharge has occurred so that groundwater conditions are near equilibrium and increase in streamflows in the Cosumnes River and Sacramento River reflect these conditions.

At both 2030 and 2070 climate change conditions, in comparison to historical hydrology data and models, the WSIP data and model products indicate significant changes in climate conditions in the level and variability of temperature and precipitation over the Program area and the Central Valley and sea level rise at the outflow of the Sacramento and San Joaquin Rivers in the Delta.

The net change in surface waters and variations thereof over the life of the Program will have different effects on the American River, Sacramento River, Cosumnes River, and Sacramento – San Joaquin River Delta (Delta). Depending on the point in time over the life of the Program, these changes, even temporarily, could have potential benefits or impacts on flows entering the Delta and the water operations of the Central Valley Project (CVP), State Water Project (SWP) and others who are dependent on the Delta for water. Potential effects vary with year by year hydrologic, regulatory and CVP and SWP and other water operations conditions. The timing of hydrologic, regulatory and water operations conditions may change the effects of the Program. Program effects are expected to be the greatest during sequences of drier hydrologic conditions (D-1641 Sacramento Valley 40-30-30 Index, Dry or Critically Dry year types; SWRCB, 1999) with stringent regulatory requirements (Reasonable and Prudent Alternatives; FWS, 2008 and NMFS 2009) and low CVP and SWP storage conditions. The evaluation presented in the document was designed to capture all aspects of the potential effects of the Program.

Assumptions

The groundwater analysis and this related surface water analysis was developed under the guidance of the Regional San project team. The following is a summary of the assumptions used for modeling of surface water conditions and evaluating the Program for the purposes of an application for funding under the WSIP. This presentation is a summary. More detailed information is available in the model-related files prepared for this evaluation. Much of the detailed information is the result of the groundwater analysis prepared for the Program. A

[2] Driest hydrologic conditions are years in which the American River Folsom Lake forecasted unimpaired inflow for the March through November period falls below 950,000 AF or the SWRCB D-1641 Sacramento Valley 40-30-30 index forecast indicates a Critically Dry year condition; anticipated to be up to 30 percent of the years over the life of the Project

companion document presents the assumptions used for modeling of groundwater conditions (see: *Integrated Groundwater and Surface Water Modeling Results Technical Memorandum,* Woodard & Curran, 2017).

Scenarios

With Project and Without Project scenarios are defined for the 2030 and 2070 climate conditions using the hydrology data and model products provided by the WSIP. The following scenarios have been defined for this evaluation:

- 2030 climate conditions
  - Without Program (provided by the WSIP)
  - Program at start of operations
  - Program after ten years of operations
  - Program after twenty years of operations or at which point groundwater is assumed to be at near-equilibrium conditions
- 2070 climate conditions
  - Without Program (provided by the WSIP)
  - Program at fifty years of operations (groundwater is assumed to be at near-equilibrium conditions)

For the evaluation of model results, With Project scenario results are compared to Without Project scenario results at each respective climate condition. Comparisons are not made between climate conditions as this would distort the evaluation of the effects of the Program.

All Program scenarios include (unless otherwise indicated):

- Regional San recycling of treated wastewater, and use of these flows for in-lieu groundwater recharge, irrigation and winter recharge; specifically
  - A portion of the existing discharge to the Sacramento River, 50,000 AFY, is diverted for recycling and
  - Modification of monthly pattern of discharge reductions to reflect mitigation measure HYD-4[3] (Regional San, 2016)
- Extraction of groundwater by entities such as the City of Sacramento (City), Sacramento County Water Agency (SCWA), or their respective customers in Driest[2] years (not included in Year 0 Start of Operations scenario)
  - Extraction of up to 32,570 AFY (equal to the average annual in-lieu recharge volume)
  - Extraction is used to reduce surface water diversions at intakes at or upstream of the Sacramento River at Freeport
- Increase in streamflows in the Cosumnes River and Sacramento River because of increased groundwater conditions in the region (not included in Year 0 Start of

[3] Mitigation measure HYD-4 presented in the EIR (Regional San, 2016) is triggered in years in which storage conditions in Lake Shasta fall below or near 2,400,000 AF on April 1; under this measure Regional San could reduce deliveries of recycled wastewater to farmers and continue a portion of the existing discharges to the Sacramento River to provide additional flexibility for river operations in driest hydrologic conditions

Operations scenario; Year 10 scenario reflects groundwater conditions after ten years of recharge operations; Year 20 and 50 scenarios reflect near-equilibrium conditions)

More details of the assumptions used for the Program scenarios are included in the following paragraphs.

The four Program scenarios are summarized in Table 1. The values provided are average annual values for the 82-year hydrologic record included in the CalSim-II model based on information provided by the groundwater analysis. In order to simulate the period of record included in CalSim-II, assumptions were selected to characterize the groundwater results as closely as possible for a period analysis approach (see the Approach section). More information on model results is included in the results section of this document.

Table 1. Regional San Program Scenarios Evaluated (values shown are annual averages over the 82 years of hydrologic record simulated with CalSim-II)

	Start of Operations	After Ten Years of Operations	After Twenty Years of Operations	When Groundwater is at Near-Equilibrium
Climate Condition	2030	2030	2030	2070
Period in Program Timeline	Year 0	Year 10	Year 20 (near-equilibrium)	Year 50 (near-equilibrium)
Wastewater Recycling / Discharge Reduction (AFY)	50,000	50,000	50,000	50,000
Frequency of Mitigation Measure HYD-4[3]	5%	5%	5%	13%
Frequency of Banked Water Groundwater Extraction/ Diversion Reduction	n/a	22%	22%	30%
Banked Water Groundwater Extraction/ Diversion Reduction (AFY)	0	7,150	7,150	9,930
Net Groundwater Recharge (AFY)	50,000	42,850	42,850	40,070
Increase in Cosumnes and Sacramento River Stream-flows (AFY)	0	17,870	34,880	32,390
Net Change in Surface Water (AFY)	(50,000)	(24,980)	(7,970)	(7,680)

At full Program buildout of Regional San deliveries of recycled water to farmers, the annual existing discharge of treated wastewater to the Sacramento River at Freeport would be reduced by 50,000 AFY, which is a portion of the overall wastewater discharge at that location (132,000 AFY under current conditions and about 200,000 AFY when Regional San reaches its permitted WWTP capacity of 181 million gallons per day, average dry weather flow). Even though the annual volume of recycling and the associated discharge reduction is assumed not to change, the monthly pattern of discharge reduction varies based on agricultural demands which vary with changes in hydrologic and climatic conditions. The monthly pattern of discharge reduction also varies per the mitigation measure HYD-4[3] (explained in the following paragraph). For CalSim-II modeling, a generalized average monthly pattern is assumed to be sufficient. The monthly pattern assumed is specific to the climate condition evaluated. CalSim-II modeling discharges are reduced during every month on the patterns shown in Table 2a for WSIP 2030 climate conditions and in Table 3a for WSIP 2070 climate conditions.

Mitigation measure HYD-4, as presented in the EIR (Regional San, 2016), is triggered in years in which storage conditions in Lake Shasta fall below or near 2,400,000 AF on April 1. Under these conditions Regional San could reduce deliveries of recycled water to farmers and continue a portion of the existing discharges to the Sacramento River. This measure provides additional flexibility in driest hydrologic conditions, to allow for The United States Bureau of Reclamation's (Reclamation) Central Valley Operations (CVO) office to manage Shasta Lake storage, temperature conditions in the Sacramento River (between Keswick Dam and Bend Bridge) and Delta outflow and exports. When HYD-4 is triggered, a portion of the Program recycled water is discharged to the Sacramento River for the months of April and May and possibly additional months through October. For CalSim-II modeling, a portion of the existing discharges are continued for the months of April through October. To ensure total delivery of recycled water for the year is 50,000 acre-feet (AF), delivery of recycled water for winter recharge is increased (and wastewater discharge reduced) in the following months of November through March such that the total annual discharge reduction (April through the following March) is 50,000 acre-feet (AF). In consideration of the uncertainty in hydrologic and operational conditions associated, a forward-looking estimate of Shasta Lake drawdown in April, May and the early part of June is considered for this measure. The trigger for HYD-4, as simulated here, may occur at the beginning of April, beginning of May, or the end of May (beginning of June). For CalSim-II modeling, modified patterns of discharge reductions for HYD-4 triggered in the beginning of April are shown in Table 2b for WSIP 2030 climate conditions and in Table 3b for WSIP 2070 climate conditions. These patterns reflect a 50 percent cut back in the discharge reductions during the April through October period (assuming the Program is fully built out; at 50 percent buildout, there would be no reductions). Under WSIP 2030 climate conditions HYD-4 occurs in 5 percent of the years (4 out of 82 years) of the hydrologic record simulated. Under WSIP 2070 climate conditions these conditions occur in 13 percent of the years (11 out of 82 years) of the hydrologic record simulated.

Extraction of groundwater by the City, SCWA, or their respective customers in Driest[2] years is one conjunctive use element of the Program, used to reduce surface water diversions at the City's and SCWA's intakes. Driest hydrologic conditions are years in which the American River Folsom Lake forecasted unimpaired inflow for the March through November period falls below 950,000 AF or the SWRCB D-1641 Sacramento Valley 40-30-30 index forecast indicates a Critically Dry year condition. The average values shown in Table 1 for groundwater extractions reflect that the frequency of groundwater extraction shown is less than 100 percent and many years there are no groundwater extractions. Each year of groundwater extraction is simulated as equal to 32,570 AFY. For example, for Year 10, extractions occur in 22 percent of the years at 32,570 AFY, and therefore the average of all years is only 7,150 AFY. This operation is not included in the Year 0 Start of Operations simulation. For the Year 10 simulation, it is assumed that sufficient groundwater has been banked to support multiple years of extraction. This assumption is informed by observation of the groundwater modeling of the Program (see: *Integrated Groundwater and Surface Water Modeling Results Technical Memorandum,* Woodard & Curran, 2017). The City, or other wholesale customers of the City, are assumed to have the capability to extract up to 10,150 AFY from groundwater and simultaneously reduce surface water diversions for the same amount. SCWA is assumed to have the capability to extract up to 22,420 AFY from groundwater and simultaneously reduce surface water diversions for the same amount. Surface water diversion reductions are assumed at intakes at or upstream of the Sacramento River at Freeport. Groundwater extractions and associated diversion reductions are assumed to be up to the amount of supply. For CalSim-II modeling diversions are reduced during every month from March through February on the pattern shown in Table 4 for WSIP 2030 climate conditions or WSIP 2070 climate conditions. A generalized average monthly pattern is assumed to be sufficient. The monthly pattern is assumed to not change with climate conditions. Under WSIP 2030 climate conditions groundwater extractions and associated diversion reductions occur in 22 percent of the years (18 out of 82 years) of the hydrologic record simulated. Under WSIP 2070 climate conditions these conditions occur in 30 percent of the years (25 out of 82 years) of the hydrologic record simulated. The difference in frequency of occurrence is driven by the impacts of climate change as projected over the 82-year hydrologic record based on the hydrologic record of the 1922 through 2003 water years used in CalSim-II.

With recharge of the groundwater basin and increase groundwater conditions over time, flows in and out of the groundwater basin are changed. A result is reduced streamflow losses to groundwater and increased streamflows in the Cosumnes River and Sacramento River. The increase in streamflows is subject to hydrologic and climatic conditions, however streamflows generally increase through time until the groundwater is at near-equilibrium conditions. The increase in streamflows may change in the long term as the frequency of groundwater extractions and climate conditions change. Approximately 95 percent of the increase in streamflows is accrued to Cosumnes River (33,133 of 34,877 AFY at Year 20) and 5 percent to the Sacramento River (1,744 of 34,877 AFY at Year 20). For CalSim-II modeling, the increase in streamflows is varied by the point in time of the life of the Program, by the hydrologic condition of each year modeled and by the climate condition modeled. At the Year 0 Start of Operations, streamflows have not increased as groundwater levels are not yet increased, however each year of additional recharge increases groundwater levels and streamflows begin to increase. After ten years of Program operations, streamflows have increased up to approximately 50 percent of near-equilibrium levels (17,873 AFY at Year 10 compared to 34,877 AFY at Year 20). Average increase in streamflows at ten years of Program operations under 2030 climate conditions are shown in Table 5a. At near-equilibrium conditions, the resultant net recharge from the Program is approximately sufficient to balance flows in and out of the groundwater basin in a steady state manner in the long run. The average increase in streamflows at near-equilibrium conditions under 2030 and 2070 climate conditions are shown in Table 5b and Table 5c respectively.

Table 2a. Regional San Discharge Reductions under 2030 Climate Conditions.

Month	Percentage of annual discharge reduction by month	Monthly discharge reduction in AF	Monthly discharge reduction in CFS
January	7.09%	3,544	57.6
February	7.09%	3,544	63.3
March	7.18%	3,590	58.4
April	4.10%	2,052	34.5
May	12.11%	6,055	98.5
June	12.79%	6,397	107.5
July	12.79%	6,397	104.0
August	12.85%	6,425	104.5
September	7.78%	3,892	65.4
October	2.02%	1,008	16.4
November	7.10%	3,550	59.7
December	7.09%	3,546	57.7
TOTAL ANNUAL	100%	50,000	

Table 2b. Regional San Discharge Reductions when Mitigation Measure HYD-4[3], as Simulated in this Effort, is in Effect starting in April under 2030 Climate Conditions (January through March values assume measure already in effect).

Month	Percentage of annual discharge reduction by month	Monthly discharge reduction in AF	Monthly discharge reduction in CFS
January	13.51%	6,757	109.9
February	13.51%	6,757	120.6
March	13.69%	6,844	111.3
April	2.05%	1,026	17.2
May	6.06%	3,028	49.2
June	6.40%	3,198	53.7
July	6.40%	3,198	52.0
August	6.42%	3,212	52.2
September	3.89%	1,946	32.7
October	1.01%	504	8.2
November	13.54%	6,768	113.7
December	13.52%	6,761	110.0
TOTAL ANNUAL	100%	50,000	

Table 3a. Regional San Discharge Reductions under 2070 Climate Conditions.

Month	Percentage of annual discharge reduction by month	Monthly discharge reduction in AF	Monthly discharge reduction in CFS
January	7.18%	3,592	58.4
February	7.18%	3,592	64.1
March	7.25%	3,623	58.9
April	5.68%	2,838	47.7
May	11.61%	5,803	94.4
June	11.61%	5,803	97.5
July	11.61%	5,803	94.4
August	12.82%	6,409	104.2
September	7.72%	3,859	64.9
October	2.97%	1,485	24.2
November	7.20%	3,598	60.5
December	7.19%	3,594	58.5
TOTAL ANNUAL	100%	50,000	

Table 3b. Regional San Discharge Reductions when Mitigation Measure HYD-4[3], as Simulated in this Effort, is in Effect starting in April under 2070 Climate Conditions (January through March values assume measure already in effect).

Month	Percentage of annual discharge reduction by month	Monthly discharge reduction in AF	Monthly discharge reduction in CFS
January	13.57%	6,785	110.4
February	13.57%	6,785	121.1
March	13.69%	6,844	111.3
April	2.84%	1,419	23.8
May	5.80%	2,901	47.2
June	5.80%	2,901	48.8
July	5.80%	2,901	47.2
August	6.41%	3,204	52.1
September	3.86%	1,930	32.4
October	1.49%	743	12.1
November	13.59%	6,797	114.2
December	13.58%	6,789	110.4
TOTAL ANNUAL	100%	50,000	

Table 4. Diversion Reductions during Driest[2] Years starting in March under 2030 and 2070 Climate Conditions.

Month	Percentage of annual diversion reduction by month	Monthly diversion reduction in AF	Monthly diversion reduction in CFS
January	3.89%	1,266	20.6
February	4.21%	1,372	24.5
March	5.61%	1,827	29.7
April	6.27%	2,043	34.3
May	10.63%	3,463	56.3
June	12.11%	3,944	66.3
July	13.57%	4,420	71.9
August	13.76%	4,482	72.9
September	10.46%	3,407	57.3
October	8.89%	2,896	47.1
November	5.82%	1,896	31.9
December	4.78%	1,556	25.3
TOTAL ANNUAL	100%	32,572	

Table 5a. Increase in Streamflows to Cosumnes River and Sacramento River under 2030 Climate Conditions with Program Groundwater at Ten Years of Program Operations.

Month	Percentage of annual increase in streamflows by month	Average monthly increase in streamflows in AF	Average monthly increase in streamflows in CFS
January	11.03%	1,972	32.1
February	11.95%	2,135	38.1
March	14.13%	2,526	41.1
April	12.64%	2,259	38.0
May	10.72%	1,916	31.2
June	7.93%	1,417	23.8
July	5.60%	1,001	16.3
August	3.06%	547	8.9
September	2.69%	481	8.1
October	3.97%	710	11.6
November	6.26%	1,119	18.8
December	10.01%	1,789	29.1
TOTAL ANNUAL	100%	17,873	

Table 5b. Increase in Streamflows to Cosumnes River and Sacramento River under 2030 Climate Conditions with Program Groundwater at Twenty Years of Program Operations and Near-Equilibrium Conditions.

Month	Percentage of annual increase in streamflows by month	Average monthly increase in streamflows in AF	Average monthly increase in streamflows in CFS
January	11.80%	4,115	66.9
February	11.82%	4,121	73.6
March	13.51%	4,712	76.6
April	11.81%	4,118	69.2
May	10.59%	3,692	60.0
June	8.32%	2,902	48.8
July	6.25%	2,179	35.4
August	3.94%	1,375	22.4
September	2.94%	1,024	17.2
October	3.61%	1,259	20.5
November	6.21%	2,165	36.4
December	9.22%	3,215	52.3
TOTAL ANNUAL	100%	34,877	

Table 5c. Increase in Streamflows to Cosumnes River and Sacramento River under 2070 Climate Conditions with Program Groundwater at Fifty Years of Program Operations and Near-Equilibrium Conditions.

Month	Percentage of annual increase in streamflows by month	Average monthly increase in streamflows in AF	Average monthly increase in streamflows in CFS
January	11.45%	3,710	60.3
February	12.82%	4,151	74.1
March	15.70%	5,085	82.7
April	14.04%	4,547	76.4
May	12.15%	3,936	64.0
June	8.52%	2,760	46.4
July	5.55%	1,799	29.3
August	3.10%	1,004	16.3
September	2.27%	735	12.4
October	2.53%	819	13.3
November	4.04%	1,307	22.0
December	7.83%	2,535	41.2
TOTAL ANNUAL	100%	32,390	

Approach

Two surface water models were used for this evaluation: CalSim-II and HEC5Q. The CalSim-II model is used to simulate the hydrology of the Central Valley and the water operations of the CVP, SWP and the Delta. The HEC5Q model is used to simulate water temperature conditions in the Sacramento River and the American River. A companion document presents the modeling of groundwater conditions using the SacIWRM model (see: *Integrated Groundwater and Surface Water Modeling Results Technical Memorandum*, Woodard & Curran, 2017).

The surface water modeling used an approach called "period" analysis, where simulations are conducted to capture a point of time in the life of the Program and a hydrologic sequence captures hydrologic variations that may occur at that point in time (climate, regulations and all other aspects of the Program setting). The application of this analysis to ground water modeling is different in that groundwater is significantly slower to respond to Program conditions than surface water, such as a twenty year, or longer, period of increase groundwater levels prior to near-equilibrium conditions. These models are formulated based on these concepts and use different time periods of the hydrologic record. For the surface water models, the hydrologic record of water years 1922 through 2003 was used, and for the groundwater model, the hydrologic record of water years 1970 through 2011 was used.

This section is a summary of the surface water models and modifications to support this evaluation.

CalSim-II Model Background and Limitations

The SWP and CVP hydrology and system operations model, CalSim-II, was developed to simulate and evaluate changes to the water resources system of California under alternative conditions. The model simulates operations of the SWP, CVP, and other water districts/facilities in the Central Valley and approximates changes in the major storage reservoirs, river flows, and exports from the Delta that would result from a change in hydrologic conditions, water supply demands, facilities, requirements or operational policies. Due to the wide range of uncertainty in projecting existing and future conditions in model inputs, model results have limited usefulness in predicting the probability of existing and future compliance with regulatory and operational objectives. Therefore, the use of the CalSim-II model results should be limited to long-term planning analyses and evaluating changes and trends over a broad range of conditions.

The California Water Commission (Commission) published a series of CalSim-II models for the WSIP (CWC, 2016c). Use of these models is required for submission of applications to the Commission for the WSIP. Adhering to this requirement, the models "WSIP 2030" and "WSIP 2070" were used to represent the Without Program condition for this evaluation. Except for climate related inputs, the CalSim-II models published by the Commission are consistent with the models previously published by the California Department of Water Resources (DWR) for the State Water Project Delivery Capability Report 2015 (DCR 2015) (DWR, 2015a and 2015b). The assumptions related to CVP and SWP operations and regulations are consistent between the DCR 2015 and the WSIP models. The DCR 2015 model is based on historical hydrology and current sea level conditions; the WSIP models incorporate changes in hydrology and sea level rise associated with projected 2030 and 2070 climate conditions. These models are documented in the WSIP Technical Reference (CWC, 2016b). The specific CalSim-II models used in this evaluation are identified as WSIP_2030_CALSIM_10-24-16 (CWC, 2016c) and WSIP_2070_CALSIM_10-24-16 (CWC, 2016c).

The CalSim-II model assumptions are consistent with the Biological Assessment on the Continued Long Term Operations of the CVP and the SWP (Reclamation, 2008a) as modified by the December 2008 USFWS BiOp Reasonable and Prudent Alternative (RPA) (FWS, 2008) and the June 2009 NMFS BiOp RPA (NMFS, 2009) and many other requirements and operating criteria governing the CVP and SWP facilities operations on the Sacramento, Feather, and American Rivers and the Delta (SWRCB, 1999; DWR, 2015b). Inputs describe assumptions of hydrology at projected levels of climate, land and water use, existing and proposed facilities, and riverine and Delta regulatory conditions. CalSim-II is a regional scale, monthly time-step model that uses projected hydrologic data based on the hydrologic record of the 1922 through 2003 water years (82-year hydrologic record). The model evaluates CVP and SWP operations throughout the hydrologic record as if projected conditions (existing or future), including population, land and water use, regulatory requirements, facilities and operating agreements, were present throughout the entire hydrologic record. The CalSim-II model results are used to identify operational controls and trace the effect of flow changes through a wide range of hydrologic and operational conditions. The simulation model is valuable to consider reservoir and other dynamic responses of an alternative (i.e., Delta salinity controls, water supply allocations, etc.) (Reclamation. 2008b).

The CalSim-II model provides a projection of how the water resources system would have behaved in the future. The model does not provide a prediction of what future operations will be. The model is used for comparative analysis and demonstration of potential effects in the setting of hydrologic information considering historical variability and the effects of climate change and sea level rise.

The CalSim-II model is a simplified and generalized representation of a complex system and not all changes indicated can be attributed to the Program. Even simplified, the model includes numerous conditional logic statements to capture the choices that SWP and CVP operators face in the real-world. The model uses storage, flow, and other information, such as estimates of salinity conditions, to make decisions for each timestep. Sometimes small changes as the result of Program being analyzed can lead to large reactions in the model that exaggerate or distort how the Program effects may occur. One example is the relationship between Delta export and stored water releases when the Delta and related CVP and SWP operations are being "controlled" for salinity compliance under D1641 (SWRCB, 1999). The model must make a judgement about whether it is worth the cost to increase Delta export and outflow to maintain salinity compliance. If the ratio of increases in stored water release to increases in Delta exports is too high the model will only export what is needed for direct use. If the ratio is in normal range, the model will export for direct use and may export to increase storage in San Luis Reservoir for future periods. The difference in this choice can result in a large change in the month's results for Delta export, outflow, river flow conditions, and upstream storage. The impact of this choice can ripple through a string of months and even years, typically in drought periods. In the case of this Program, the potential difference in this choice in one month can dwarf the effects of the Program for the year. Nevertheless, CalSim-II is the best available tool and is required by the WSIP for this evaluation of system effects related to the Program.

The CalSim-II model used in this evaluation has the following additional limitations specific to this application:

- The model does not consider potential temporary modifications of regulations, water rights or responsibilities of the CVP, SWP or other entities that may occur during prolonged drought conditions under current or future climate conditions; a recent example is the drought management actions of the California State Water Resources Control Board (SWRCB) in 2014 and 2015
- The model does not consider the proposed purveyor-specific agreements of the Sacramento Area Water Forum Agreement including the voluntary reduction of surface water diversions from the American River in drier hydrologic conditions

With these above limitations, the CalSim-II model results present a worst-case condition for reservoir storage and river flow operations. Therefore, the analysis of the effects of the Program are likely also worst-case condition. Potential negative effects such as impacts to upstream reservoir operations and related temperature conditions in the reaches downstream of those reservoirs is likely worst-case.

Modifications to the CalSim-II to Evaluate the Program

Due to the spatial scale assumed in its development, the CalSim-II model does not include an explicit representation of the Regional San wastewater discharge to the Sacramento River. To model a discharge reduction, a diversion was added to the CalSim-II model at a point that represents the general location and hydrologic influence of the Regional San actual discharge location (CalSim-II Sacramento River node 169). Modeling a diversion of the same magnitude will have the same operational effect in the model as if the discharge reduction was assumed. The CalSim-II does include a general representation of the surface water diversions along the American River and lower Sacramento River. However, the modeling of diversions in CalSim-II is closely coupled with regional water balance equations that do not explicitly consider groundwater recharge, banking or extractions. To avoid complex code modifications to model diversion reductions, inflows were added to the CalSim-II model at a point that represents the locations of the City intake on the American River (CalSim-II American River node 302) and FRWP intake on the Sacramento River (CalSim-II Sacramento River node 168). Modeling an inflow of the same magnitude will have the same operational effect in the model as if the diversion reduction was assumed. For modeling increases in streamflows, return flows were added to the CalSim-II model at points on the Cosumnes River and Sacramento Rivers that represent the general locations where increases would occur (CalSim-II Sacramento River node 400 and Cosumnes River node 504).

The values for simulating the Program in CalSim-II were selected based on the results of the groundwater analysis. (see: *Integrated Groundwater and Surface Water Modeling Results Technical Memorandum*, Woodard & Curran, 2017). The groundwater analysis includes a hydrologic period consistent with 1970 through 2011. This period is repeated in the analysis to simulate the ramp up and near-equilibrium conditions of the groundwater basin. CalSim-II includes a hydrologic period consistent with 1922 through 2003 and uses a "period analysis" approach described in the next section. Inputs for discharge reduction, diversion reduction, and increase in streamflows volumes and patterns as they vary by hydrologic conditions and climate conditions were developed from the results of the groundwater analysis. Values for CalSim-II were selected to characterize the groundwater results as closely as possible and to fully consider the potential effects of the Program on the surface water flows and storage conditions modeled by CalSim-II.

Due to the regional scale of the CalSim-II model and the coarse spatial representation of many river reaches, it should be noted that CalSim-II, while useful for understanding the complex water resources system of the CVP, SWP, and the Delta, additional analysis is needed with local watershed models and/or the DWR Delta Simulation Model (DSM2) to fully understand the significance of changes at a more local scale. To the extent that local scale changes are important for controlling the outcome of the water operations simulation, this lack of local scale can add to the uncertainty of the CalSim-II model results. This is not expected to be an issue in this application.

Table 6 is a list of CalSim-II model files modified (nontrivial) or added to implement the above changes consistent with the assumptions of each Program scenario modeled.

Table 6. CalSim-II Model Files Modified or Added for Program Scenarios.

CalSim-II Model File	Comment
SRCSD_AgRecyc.wresl	ADDED – This file includes all of the model logic related to the Program, including parameter settings related to point in time in the life of the Program (for increase in streamflow calculations), location split of increase in streamflows, and forward looking adjustments for determining HYD-4 trigger
SRCSD_reductions.table	ADDED – This file specifies inputs for Regional San discharge reductions by month for normal years and years in which HYD-4 is considered triggered; this file varies with climate condition
SRCSD_extractions.table	ADDED – This file specifies inputs for extractions and diversion reductions for City and SCWA, or their respective customers; this file varies with point in time in the life of the Program – set to zero if at Year 0 Start of Operations of the Program
SRCSD_streamflows.table	ADDED – This file specifies inputs for coefficients for determining increase in streamflows; this file varies with climate conditions; includes month and year type varying values; these values and other parameters are used in calculations in SRCSD_AgRecyc.wresl file to determine the increase in streamflows for each month of the simulation
Delivery-table.wresl	MODIFIED – This file modified to setup variables for Regional San discharge reductions
Inflow-table.wresl	MODIFIED – This file modified to setup variables for diversion reductions for City and SCWA, or their respective customers
Return-table.wresl	MODIFIED – This file modified to setup variables for increase in streamflows to the Sacramento River and Cosumnes River

<table>
<tr><td>CalSim-II Model File</td><td>Comment</td></tr>
<tr><td>Connectivity-table.wresl</td><td>MODIFIED – This file modified to include variables for the Program into the correct locations (nodes/arcs) in the CalSim-II schematic</td></tr>
<tr><td>AnnCommon2.wresl</td><td rowspan="2">MODIFIED – These files include variables for the Program to ensure the model logic for various operations works correctly</td></tr>
<tr><td>weir_steps.wresl</td></tr>
</table>

During the simulation, when the combination of changes to the surface water flows (due to discharge reductions, diversion reductions and increase in streamflows) occurs during “balanced” conditions (periods when it is agreed that releases from upstream reservoirs plus unregulated flow approximately equal the water supply needed to meet Sacramento Valley inbasin uses, plus exports; Reclamation and DWR, 1986) a reduced surface water flow change will have the effect of increasing stored water releases. Similarly, in such a situation an increased surface water flow change will have the effect of decreasing stored water releases. When the change occurs during “excess” conditions (when there is adequate flow in the Delta such that CVP and SWP reservoirs are not releasing stored water) a reduced (increased) surface water flow change will have the effect of decreasing (increasing) flows into the Delta (“balanced” and “excess” conditions are determined by applying the rules of the 1986 Coordinated Operating Agreement between the CVP and SWP; Reclamation and DWR, 1986). The various combinations of conditions are shown in Table 7.

Table 7. Response to Changes to Surface Water Flows under “Balanced” and “Excess” Conditions under the Coordinated Operating Agreement.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Net Surface Water Change due to the Program</td></tr>
<tr><td>Reduction in Surface Water Flows</td><td>Increase in Surface Water Flows</td></tr>
<tr><td rowspan="2">Coordinated Operating Agreement Operational Condition</td><td>Period is in “balanced” conditions;
CVP and SWP reservoirs are releasing stored water for in-basin use requirements</td><td>Increase in CVP and SWP stored water releases</td><td>Decrease in CVP and SWP stored water releases</td></tr>
<tr><td>Period is in “excess” conditions;
adequate flow in the Delta such that CVP and SWP reservoirs are not releasing stored water</td><td>Decrease in flows into the Delta</td><td>Increase in flows into the Delta</td></tr>
</table>

Discussion of the CalSim-II Approach

An approach called “period analysis” was used for each point of time in the life of the Program (see Assumptions sections). Period analysis uses the hydrologic record (1922 through 2003) to simulate a projected condition at a selected period (e.g. Year 2030). The projected condition is the assumptions, model inputs and simulated model outputs that are used to represent the selected period. A period analysis approach uses the historical range of hydrologic variability projected to a selected climate condition, uses a modified sea level with hydrologic- and tidally-driven variations to reflect a selected sea level rise condition, and uses a constant level-of-development imposed on each year of the hydrologic record to simulate the project condition. Level-of-development includes assumptions and inputs associated with the selected land and water use, water control facilities, regulatory requirements, operations policies and other factors for simulation. The level-of-development is developed based on observed records (USGS gauges, operations reports, etc.), adjusted for estimated changes in demands, diversions, flows, storage, and any other factor that influences the occurrence and magnitude of water.

In applying a period analysis approach, the CalSim-II modeling community uses standardized protocols in preparing modifications to the model and application to specific projects. This typically includes retraining of a model input referred to as the Water Supply Index – Delivery Index (WSIDI) lookup table. For this application of the CalSim-II model, the WSIDI inputs were not modified. In day-to-day operations, CVP and SWP operators have limited knowledge regarding real-time inflows, and valley accretions/depletions to describe the balance of flows between upstream reservoir releases and resultant inflows to the Delta. The Program modifies this balance of flows per the amount of change in the surface water flows (due to discharge reductions, diversion reductions and increase in streamflows). However, without more detailed knowledge of the overall balance of flows, the effect of this modification may be uncertain. The annual balance of flows is forecasted as part of the CVP and SWP operators' determination of available supply for allocating to water supply contracts. These allocations drive the operations of Delta exports. The CVP and SWP allocation logic in CalSim-II is a gross simplification of the operators' decision process. In this simplified process, the WSIDI input describes a coarse relationship between storage and forecasted inflows and the available supply for allocating to storage carryover and water supply contracts. To ensure that the potential effects of the Program were fully quantified in the differences between the Program and Without Program CalSim-II model results, the WSIDI input was unmodified for the following reasons: 1) the response of water supply allocation decisions is unclear without a description of how the Program and CVP and SWP operators would communicate about the Program effects on surface water flows in real-time operations and 2) due to the relative coarseness of the WSIDI input in comparison to the magnitude of the Program's effects, retraining of the WSIDI inputs would have the effect of attenuating the Program effects and obfuscating the reviewers' ability to identify and explain the direct cause of Program effects.

HEC5Q Model Background and Limitations

Over the last 15 years, the Reclamation has developed applications of the US Army Corps of Engineers HEC5Q model for evaluation of water temperatures on the Sacramento River, American River, and Stanislaus Rivers. Reclamation made substantial revisions to these models for use in their NEPA EIS analysis of the Coordinate Long-Term Operations of the Central Valley Project and State Water Project (LTO EIS) (Reclamation, 2015). The HEC5Q model was designed to work with the model results of the CalSim-II model and was calibrated for historical meteorological conditions. For the LTO EIS analysis, procedures were established to incorporate operational assumptions related to selective withdrawal features at Shasta Lake (temperature control device) and Folsom Lake (temperature control shutters).

The regulations for the WSIP require that the models used in the evaluation of the Program incorporate changes associated with the WSIP 2030 and 2070 climate conditions. This required establishing Without Program versions of the HEC5Q models that reflected the change in temperatures associated with the WSIP 2030 and 2070 climate conditions. The LTO EIS HEC5Q models for the Sacramento River and American River were modified to adjust for increases in temperature associated with each climate condition. Further, the operational assumptions related to selective withdrawal features at Shasta Lake and Folsom Lake were adjusted to consider the effects of each climate condition on the management of reservoir release temperatures and the extent to which water temperature objectives could be achieved within the critical reaches downstream of these reservoirs (see: *Development of WSIP Climate Scenarios for use in HEC5Q Technical Memorandum,* CH2M, 2017).

The HEC5Q models calculate the change over time in water temperatures in reservoirs and rivers based on estimates of equilibrium water temperature and the rate at which heat exchange in the water will change as it approaches equilibrium. These estimates are based on meteorological and environmental information associate with the geographic location being studied. Based on temperature information included in the WSIP statewide gridded monthly data products (CWC, 2016c) model inputs for equilibrium temperatures were adjusted for the WSIP climate scenarios. More information on these adjustments is available (see: *Development of WSIP Climate Scenarios for use in HEC5Q Technical Memorandum,* CH2M, 2017).

In applying the HEC5Q models, water temperature objectives downstream of Shasta Lake and Folsom Lake are required for the model to select what elevation to withdrawal releases from. The temperature of water varies with depth in a reservoir depending on the degree to which the profile is stratified (due to temperature and density variation). Warmer water is less dense than cooler water and will move to the top of the reservoir. Much of the warming of a reservoir over the spring and early summer months comes from solar radiation through the surface of the lake. To meet temperature objectives downstream of the reservoir, water is selectively withdrawn at an elevation that provides water cool enough to meet the downstream objective. Both the Shasta Lake and Folsom Lake schedules are varied each year of simulation based on reservoir storage and inflow conditions and expected changes in water temperature that occur between the reservoirs and the objective locations in the rivers. Based on reiterative analysis, schedules of temperature objectives are modified to reflect the effects of the WSIP climate conditions. More information on these adjustments is available (see: *Development of WSIP Climate Scenarios for use in HEC5Q Technical Memorandum,* CH2M, 2017).

The HEC5Q model provides a projection of how the water temperature trends with changes in storage and flows in the water resources system. The model does not provide a prediction of what future water temperatures will be. This model is intended for use in comparative analysis and demonstration of potential effects in the setting of hydrologic information considering historical variability and the effects of climate change. It should be recognized that the HEC5Q model is a simplified and generalized representation of complex hydrodynamic and thermodynamic processes in the riverine environment. While the HEC5Q model can provide 6-hour to daily timestep information at any location within the model domain, evaluation of the model results should consider the limitations of the information used to calibrate the model and the inputs to the model for the specific conditions being evaluated. Because the CalSim-II model results used are subject to specific location and monthly timestep limitations, care must be used in drawing any conclusion from the HEC5Q model results that is finer in spatial and temporal resolution than the CalSim-II model used. Nevertheless, HEC5Q is the best available tool for this evaluation of system effects related to the Program.

Modifications to the HEC5Q to evaluate the Program

All modifications to the HEC5Q model were made for modeling WSIP 2030 and 2070 climate conditions. No additional modifications were required for with Program conditions.

Discussion of the HEC5Q Approach

As described above, the Shasta Lake and Folsom Lake schedules for temperature objectives are varied each year of simulation based on reservoir storage and inflow conditions and expected changes in water temperature that occur between the reservoirs and the objective locations in the rivers. In evaluating the Program condition, the schedules used for the respective Without Program condition were used for the Program condition as well. This assumes that there is no significant change in the strategy of temperature operations that would result from the implementation of the Program. Whether this is the case, a worse-case analysis of temperature conditions is the result.

Results

The following is a presentation of the CalSim-II and HEC5Q modeling results and findings. Please consider the limitations and scope of the approach used for this analysis. It is the judgment of the author that the approached used is adequate for the findings presented. The limitations of the approach produce a worst-case assessment of the effects of this Program. See the Approach section for more information.

Reports of Model Results

Attachment A and Attachment B is provided to support the detailed evaluation of potential effects of the Program. CalSim-II model output reports are included for the Trinity, Sacramento, Feather, and American River major reservoir storages and selected river flows; Delta flows; X2 position; Delta export; and for CVP and SWP allocations and CVP and SWP deliveries by regions. HEC5Q model output reports are included for water temperatures at key locations on the Sacramento and American Rivers. A catalog of parameters and locations presented is shown in Table 8.

Each report compares one of the four Program scenarios modeled with the respective Without Program condition. Results are tabulated/graphed using various statistics appropriate for use with CalSim-II and HEC5Q model results, including long-term averages, year-type based averages (based on SWRCB D-1641 Sacramento Valley 40-30-30 year type indices, adjusted for each climate condition) and exceedance levels (based on independent ranked ordering of values). For each model run, two attachments are provided including reports for each parameter and location:

- Summary reports (Attachment A) showing averaged results tabulated/graphed including long-term averages, year-type based averages, including absolute and relative differences between with-project and without-project conditions

- Exceedance probability reports (Attachment B) showing year-by-year results tabulated/graphed in independent ranked order of values for with-project and without-project conditions

Additional locations, parameters and chart formats are available and can be prepared upon request.

Table 8. Model Output Reports Catalog

Report Title	Report ID	Time-Step	Parameter
Regional San Program Operations			
Program Discharge Reduction at Sacramento River at Regional San at Freeport	OP-1	Monthly	Flow
Program Diversion Reductions	OP-4	Monthly	Flow
Program Net Groundwater Recharge due to Discharge Reductions and Diversion Reductions	OP-5	Monthly	Flow
Streamflow Changes due to Program Net Groundwater Recharge	OP-8	Monthly	Flow
Program Net Change in Surface Water due to Discharge Reductions, Diversion Reductions and Streamflow Changes	OP-9	Monthly	Flow
Trinity River			
Trinity Lake	TR-1	End of Month	Storage
Upper Sacramento River			
Shasta Lake	SR-1	End of Month	Storage
Sacramento River below Keswick Reservoir	SR-2	Monthly	Flow
Sacramento River at Bonnyview Bridge	ST-2	Monthly	Water Temperature
Sacramento River at Jellys Ferry	ST-4	Monthly	Water Temperature
Feather River			
Lake Oroville	FR-1	End of Month	Storage
American River			
Folsom Lake	AR-1	End of Month	Storage
American River at H Street	AR-4	Monthly	Flow
American River at Watt Avenue	AT-2	Monthly	Water Temperature

Report Title	Report ID	Time-Step	Parameter
Lower Sacramento River			
Sacramento River at Freeport	SR-8	Monthly	Flow
Sacramento – San Joaquin River Delta			
Mokelumne River near Walnut Grove (includes flow from Cosumnes River)	DC-9	Monthly	Flow
Total Banks Pumping Plant (SWP and CVP) and Jones Pumping Plant (CVP)	DC-6	Monthly	Diversion
Sacramento/San Joaquin River Delta	DC-7	Monthly	Outflow
X2	DC-8	Monthly	Position
Regional Water Supplies			
CVP Regional Deliveries	WS-CVP	Annual (Mar – Feb)	Allocations and Deliveries
SWP Regional Deliveries	WS-SWP	Annual (Jan – Dec)	Allocations and Deliveries

Potential Surface Water Flow Effects

The effect of the Program is reflected in the net change in surface water flows, both in volume and in timing. These effects of these changes are primarily to Delta outflow and Delta exports. The long-term net flow changes due to the Program for each scenario are summarized in Table 9a. The monthly pattern of long-term net flow changes due to the Program for each scenario are shown in Figure 2a.

The long-term net flow change is an impact at the start of operations equivalent to the full magnitude of discharge reductions (50,000 AFY). However, as groundwater conditions improve, increases in streamflows occur and sufficient water is banked to support extractions and associated diversion reductions of surface water. After ten years of operations the impact of the Program is reduced by more than 50 percent (from 50,000 AFY down to 24,980 AFY). After twenty years of operations the impact of the Program is reduced by more than 80 percent (down to 7,970 AFY) and remains steady through the remaining life of the Program (between 7,970 and 7,680 AFY). As Figure 2a shows, after ten years of operations, during certain months, the Program provides an increase in flow to the Delta.

The largest impact is to Delta outflow which accounts for approximately 70 percent of the reduction of surface water (35,440 AFY at Year 0, 16,270 AFY at Year 10, 3,530 AFY at Year 20 and 5,270 AFY at Year 50). The remainder of the impact is to Delta export and upstream storage operations (see following discussion). Of the impact of reduced Delta exports (9,270 AFY at Year 0, 5,650 AFY at Year 10, 2,620 AFY at Year 20 and 3,360 AFY at Year 50), about half of the impact is to the CVP and half to the SWP water service contractors (see reports WS-CVP and WS-SWP).

To put these values into perspective 50,000 AFY is less than 0.8 percent of the Dry and Critically Dry year type (D1641 40-30-30) average Delta outflow and is less than 1.3 percent of the Dry and Critically Dry year type (D1641 40-30-30) average Delta export relative to the Without Program condition.

As described previously and summarized in Table 7, flow changes during "balanced" conditions have the potential to impact upstream stored water releases. Balanced conditions are common in the summer months and driest hydrologic conditions. Reductions in surface water have the greatest potential for impact in extended droughts or sequences of drier years. Over the 82-year period of record from 1922 to 2003, sequential drought years during the periods 1929 – 1934 (May 1928 – October 1934) and 1987 – 1992 (June 1986 – September 1992) create circumstances in the CalSim-II model simulation where impacts to storage can accumulate.

Table 9a. Surface Water Flow Effects of Program Scenarios (values shown are annual average changes over the 82 years of hydrologic record simulated with CalSim-II)

	At Start of Operations	After Ten Years of Operations	After Twenty Years of Operations	When Groundwater is Near Equilibrium
Climate Condition	2030	2030	2030	2070
Period in Program Timeline	Year 0	Year 10	Year 20 (near-equilibrium)	Year 50 (near-equilibrium)
Net Change in Surface Water (AFY) *(OP-9)*	(50,000)	(24,980)	(7,970)	(7,680)
Net Change in Delta Outflow (AFY) *(DC-7)*	(35,440)	(16,270)	(3,530)	(5,270)
Net Change in Delta Export (AFY) *(DC-6)*	(9,270)	(5,650)	(2,620)	(3,360)
Other Change (NOD Deliveries & residuals) (AFY)	(5,290)	(3,060)	(1,820)	950

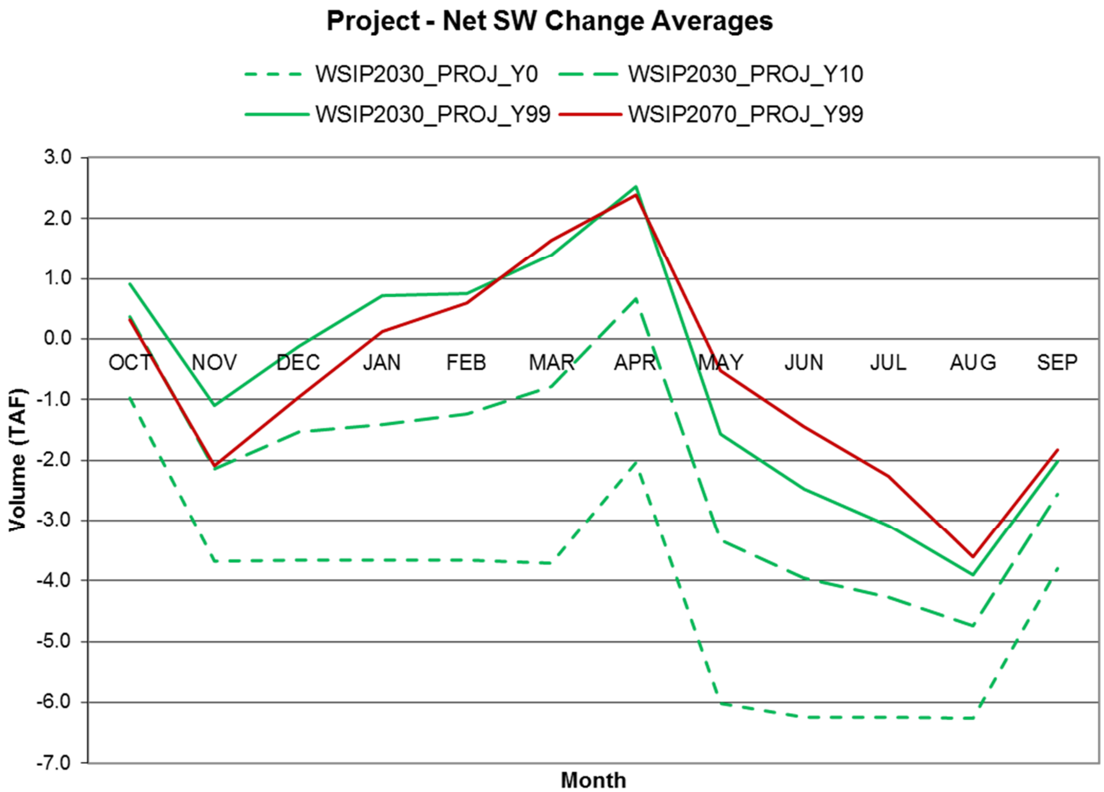

Figure 2a. Monthly Pattern of Net Surface Water Flow Effects of Program Scenarios (values shown are annual average changes over the 82 years of hydrologic record simulated with CalSim-II)

For this reason, it is also of interest to look at surface water flow effects in extended drought conditions. The net flow changes due to the Program during extended drought conditions for each Program scenario are summarized in Table 9b. The monthly pattern of net flow changes due to the Program during extended drought conditions for each Program scenario are shown in Figure 2b.

During extended drought conditions the change in surface water flows is generally more positive than over the long-term. Following near-equilibrium groundwater conditions, the groundwater-related increase in streamflows and diversion reductions balance discharge reductions in the drought conditions. The impact at the start of operations is almost equivalent to the full magnitude of the discharge reductions (49,170 AFY). Diversion reductions are triggered by drier conditions and occur more frequently in droughts. After ten years of operations the impact of the Program is reduced by almost 70 percent (from 49,170 AFY down to 15,140 AFY). After twenty years of operations the impact of the Program is reduced to a negligible amount and remains steady through the remaining life of the Program. The largest impact during drought conditions is to Delta exports. Of the impact of reduced Delta exports (24,850 AFY at Year 0, 13,970 AFY at Year 10, 2,590 AFY at Year 20 and 4,360 AFY at Year 50), about half of the impact is to the CVP and half to the SWP water service contractors (see reports WS-CVP and WS-SWP).

Table 9b. Surface Water Flow Effects of Program Scenarios (values shown are annual average changes during the longest drought sequences in the 82 years of hydrologic record simulated with CalSim-II; years 1928 - 1934 and 1986 -1992)

	At Start of Operations	After Ten Years of Operations	After Twenty Years of Operations	When Groundwater is Near Equilibrium
Climate Condition	2030	2030	2030	2070
Period in Program Timeline	Year 0	Year 10	Year 20 (near-equilibrium)	Year 50 (near-equilibrium)
Net Change in Surface Water (AFY) *(OP-9)*	(49,170)	(15,140)	720	390
Net Change in Delta Outflow (AFY) *(DC-7)*	(15,010)	(5,240)	3,310	(14,260)[1]
Net Change in Delta Export (AFY) *(DC-6)*	(24,850)	(13,970)	(2,590)	(4,360)

1 The large value is due to a transient change in SWP Delta export and related outflow and Oroville Lake storage changes that occurred in October 1930 and the following 14 months; this transient change is disproportionate to and does not correspond to the Program effects (see Attachment C-4 drought period timeseries reports)

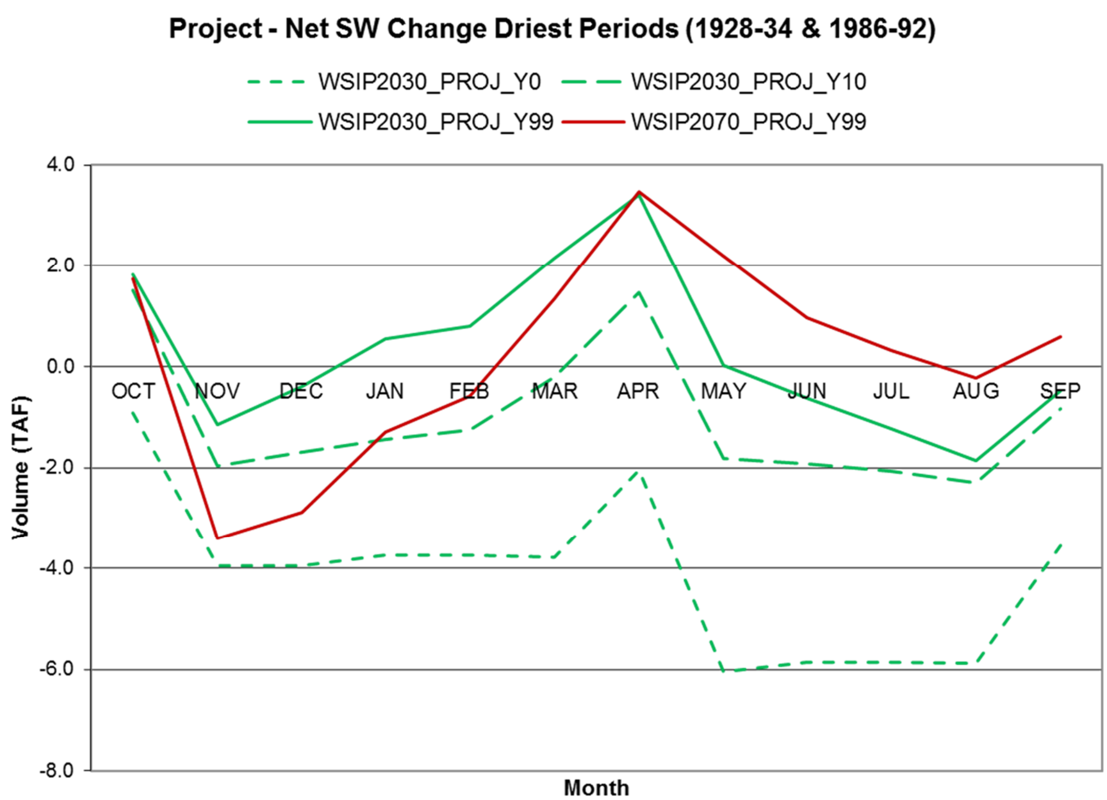

Figure 2b. Monthly Pattern of Net Surface Water Flow Effects of Program Scenarios (values shown are annual average changes during the longest drought sequences in the 82 years of hydrologic record simulated with CalSim-II; years 1928 - 1934 and 1986 -1992)

Potential Storage and Temperature Effects

Upstream CVP and SWP reservoirs are also susceptible to impacts due to the Program during drought conditions. The timing of reservoir releases follows per the month by month balance of flows in the upstream watersheds and the Delta. For example, the CVP operates Shasta Lake releases for instream flow requirements in the upper Sacramento River, for Sacramento River diverters, for Delta water quality, outflow requirements and for Delta Exports. The SWP also operates for instream flow requirements and Delta water quality, outflow requirements and Delta Exports. In wet winter and spring months, flows into the reservoirs and the river system exceed the requirements and the CVP and SWP can store water that is not needed in their reservoirs. In dry summer and fall months, requirements must be met through reservoir releases. The CVP and SWP share the water stored and the requirements for reservoir releases according to the rules of the 1986 Coordinated Operating Agreement (COA) between the CVP and SWP (Reclamation and DWR, 1986). The COA specifies the conditions and sharing formulae for "excess" and "balanced" conditions accordingly. Generally, all adverse monthly water balance changes due to the Program occur about equally between balanced and excess conditions as defined by COA. Therefore, half the time these water balance changes must be made up by CVP and/or SWP storage withdrawals. The withdrawals from CVP and/or SWP storage accumulate through dry periods. Often the impact of additional withdrawals on storage is reduced once "excess" conditions resume after the summer months and when the winter storms begin.

The accumulated storage changes due to the Program during extended drought conditions for each Program scenario are summarized in Table 10. Much of the impact of the Program on upstream storage during extended drought conditions is to Shasta Lake. The impact on Shasta Lake storage could create thermal impacts to fisheries habitat downstream of the reservoir, thus HEC5Q was used to further understand temperature conditions. The potential for impact to storage generally decreases throughout the life of the Program. The potential for impact at the start of operations appears to be great, however impact of the magnitude shown in the table take multiple critically dry conditions to develop – this is unlikely to occur within the first ten years of the Program. After ten years of operations the potential for impact of the Program on storage is reduced significantly. The potential for impact of the Program on storage continues to decrease through the life of the Program however the results indicate that the potential for impact may vary and increase with worsening climate conditions.

Table 10. Surface Water Storage Effects of Program Scenarios (values shown are maximum changes during the longest drought sequences in the 82 years of hydrologic record simulated with CalSim-II; years 1928 - 1934 and 1986 -1992)

		At Start of Operations	After Ten Years of Operations	After Twenty Years of Operations	When Groundwater is Near Equilibrium
Climate Condition		2030	2030	2030	2070
Period in Program Timeline		Year 0	Year 10	Year 20 (near-equilibrium)	Year 50 (near-equilibrium)
Shasta Lake, Maximum Change in Storage (AF) *(SR-1)*	1928-1934	(82,230)	(25,600)	(16,130)	(30,250)
	1986-1992	(57,710)	(20,900)	(19,800)	(3,720)[1]
Combined Trinity, Shasta and Folsom Lakes, Maximum Change in Storage (AF) *(TR-1, SR-1 and AR-1)*	1928-1934	(87,110)	(30,560)	(22,010)	(43,890)
	1986-1992	(86,580)	(25,110)	(21,000)	(8,520)[1]

1 The lower values are related to the transient change in October 1930 and the following 14 months described in the footnote of Table 9b; this transient change is disproportionate to and does not correspond to the Program effects (see Attachment C-4 drought period timeseries reports)

Figure 3a and Figure 3b illustrate the potential impact of reduction of storage in Lake Shasta (CVP) and the impact on water temperature in the Sacramento River at Jelly's Ferry in the hydrologic sequence of 1987 – 1992 (June 1986 – September 1992). This is the model result for the Program at the start of operations coinciding with an extended drought sequence. However unlikely, this sequence is one of the most challenging operating conditions for the CVP in the hydrologic period simulated. This amount of reduction in Shasta Lake storage could potentially create thermal impacts to downstream fisheries habitat due to the increase temperature of water in reservoir storage and due to potential decrease in flows downstream of Shasta Lake. These types of potential impacts diminish quickly after ten years of Program operations as shown in Figure 3c, and are negligible after twenty years of Program operations.

Attachment C includes additional charts showing storage conditions for Shasta Lake, water temperatures in the Sacramento River, for each Program scenario, during the modeled hydrologic sequence of 1929 – 1934 and 1987 – 1992. Charts also include storage conditions for Folsom Lake, water temperatures in the American River, and storage conditions in Lake Oroville. Summary and year-by-year Program operations information is also included.

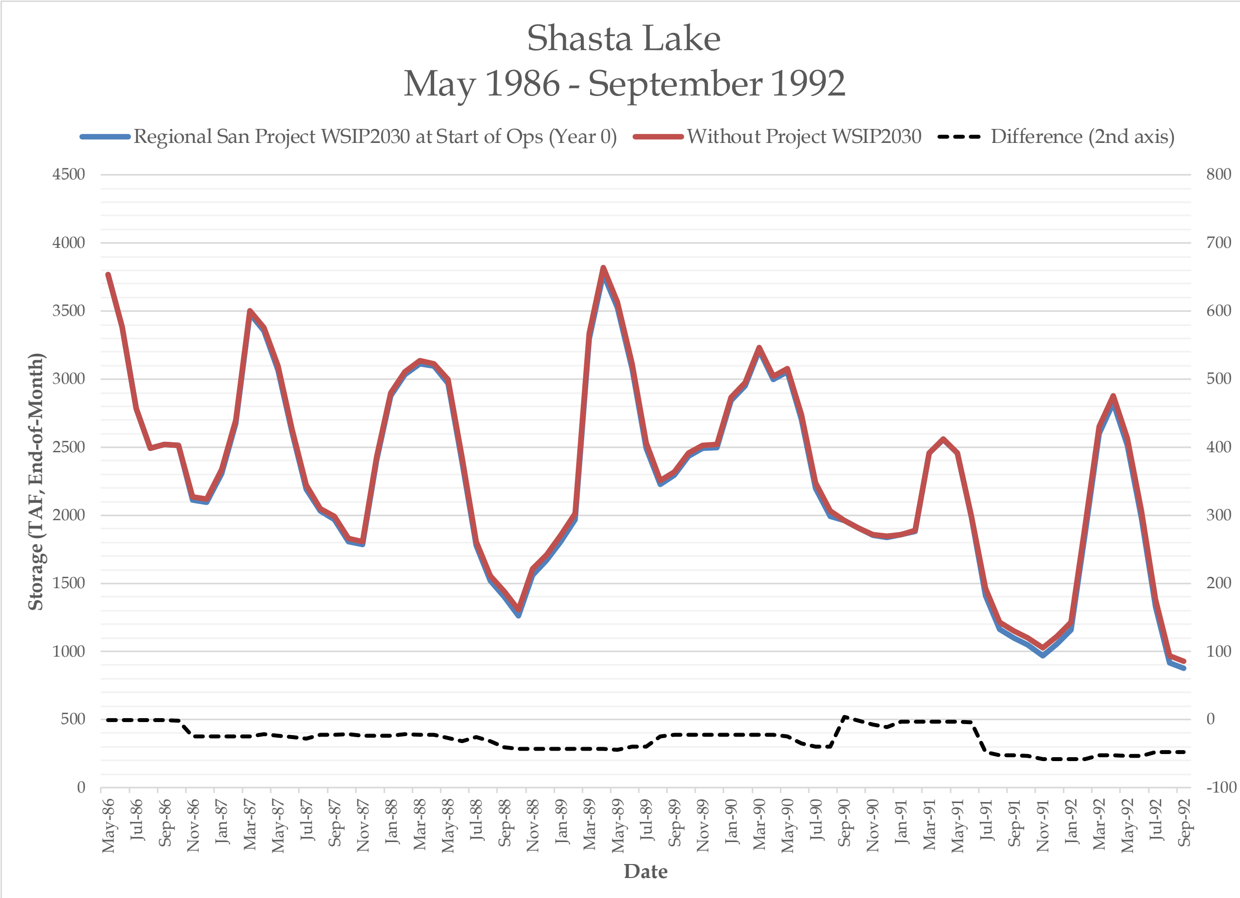

Figure 3a. CalSim-II Simulated Results for Storage at Shasta Lake, With Program at Start of Operations and Without Program Conditions, 1987 – 1992 (May 1986 – September 1992) (Both y-axis have the same units).

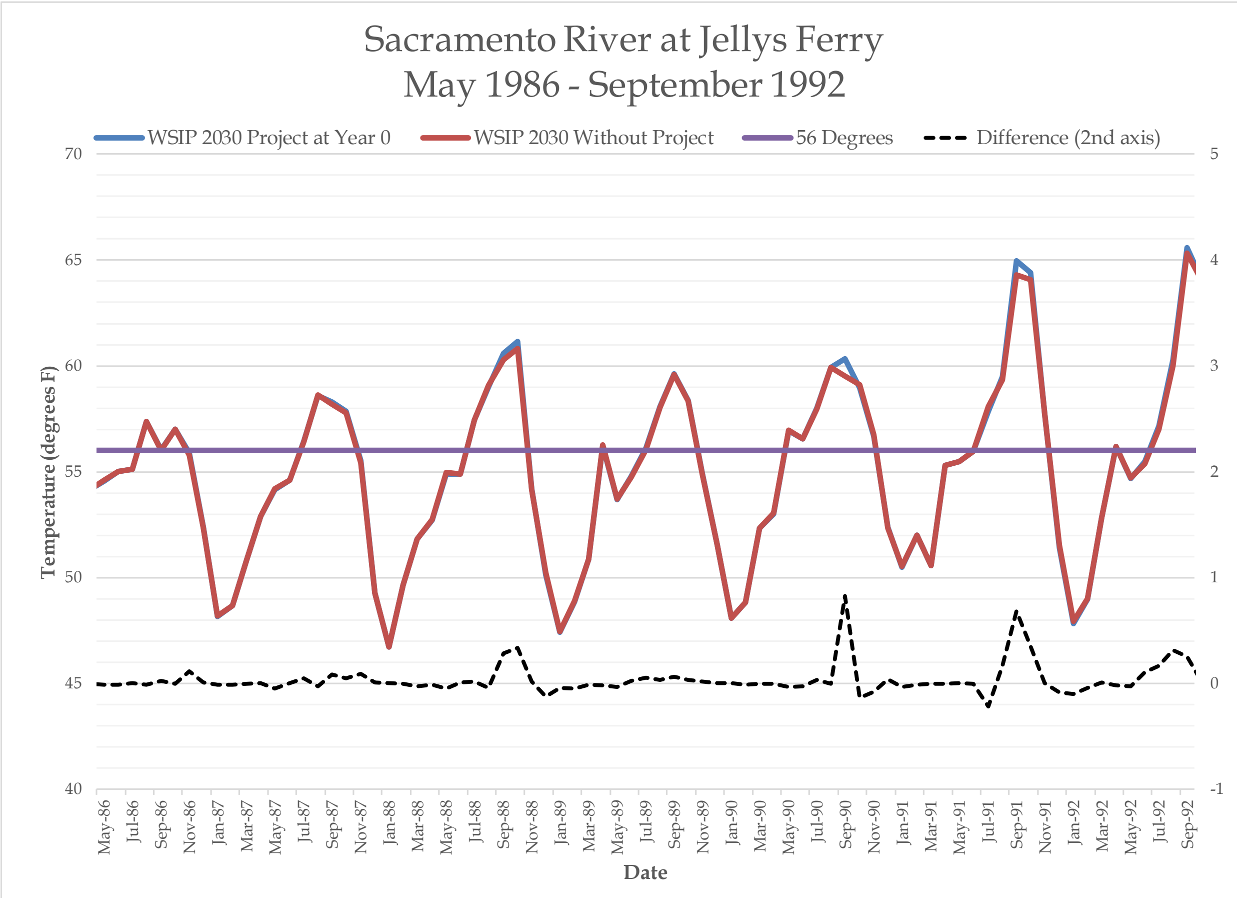

Figure 3b. HEC5Q Simulated Results for Water Temperature for Sacramento River at Jelly's Ferry, With Program at Start of Operations and Without Program Conditions, 1987 – 1992 (May 1986 – September 1992) (Both y-axis have the same units).

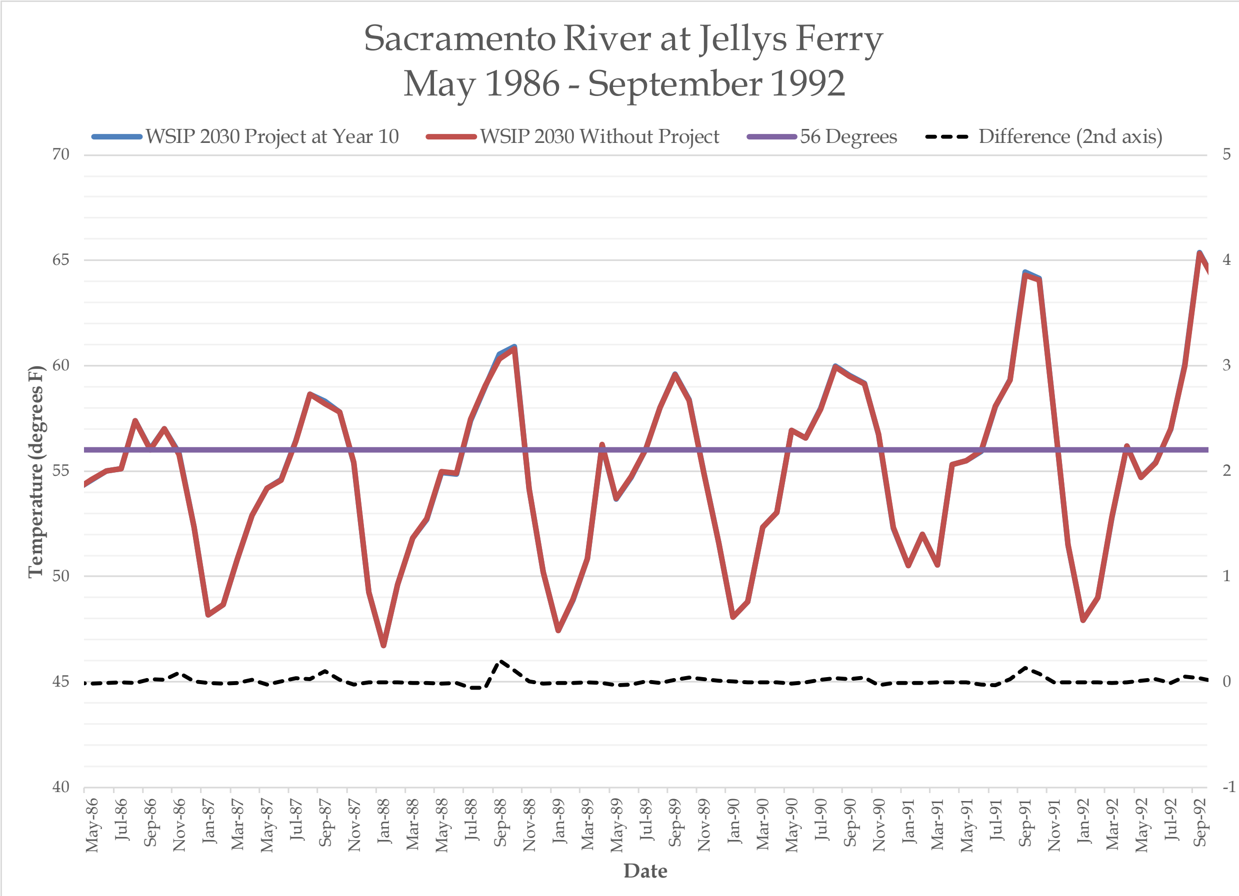

Figure 3c. HEC5Q Simulated Results for Water Temperature for Sacramento River at Jelly's Ferry, With Program after Ten Years of Operations and Without Program Conditions, 1987 – 1992 (May 1986 – September 1992) (Both y-axis have the same units).

Potential Mokelumne River Effects

The Program-related increase in streamflows is reflected in the change in Cosumnes River flows and Mokelumne River flows further downstream. The long-term change and change during extended drought conditions in flow volumes in these river courses due to the Program for each scenario are summarized in Table 11. Increase in streamflows occur in all year months and all year types is the primary benefit of the Program in the Cosumnes River basin. Monthly average increases in streamflows during Critically Dry years (D1641 40-30-30 index) (15 percent, 12 out of 82 years simulated) are shown in Figure 4. This figure shows the Program after twenty years of operations, compared to Without Program conditions, when increases in streamflows due to the Program reach the maximum simulated.

As groundwater conditions improve, increases in streamflows occur. After ten years of Program operations, about 50 percent (16,980 AFY) of the increases in streamflows expected are realized.

After twenty years, increases in streamflows reach their simulated maximum (33,130 AFY). Increases in streamflows decline by less than 10 percent from the maximum as climate conditions change in the latter half of the Program life (from 33,130 down to 30,770 AFY). After twenty years, increases in streamflows to the Cosumnes River and Mokelumne River amount to an increase of 33,130 AFY even though the average net surface water change due to the Program is a reduction of 7,970 AFY. This change has the effect of returning the Cosumnes River to a more natural pattern of flows and improves flow conditions in the Mokelumne River.

Eighty percent of the streamflow increases are maintained through extended drought conditions as compared to the long-term average (27,640 of 33,130 AFY at Year 20). However, the significance of improvements related to the increases is relatively larger. While the increases in the Mokelumne River above the Without Program condition only amount to 4 percent improvement annually in the long-term, increases are 11 percent annually in the extended drought years. In summer months of extended drought periods, the increases can average as much as 30 percent as shown in Figure 4.

The flow in the Mokelumne River downstream of the Cosumnes River increases. Further increases in the Mokelumne River occur downstream of Walnut Grove and downstream in the San Joaquin River. The relative effect of the increase in flow will diminish the further downstream. However, in driest hydrologic conditions, improvements may extend all the way down to the confluence of the Mokelumne River with the San Joaquin River.

Due to the regional scale of the CalSim-II model and the coarse spatial representation in the Cosumnes River and Mokelumne River reaches, it is recommended that further analysis be undertaken to fully understand the significance of the improvements in the Cosumnes River and downstream reaches in the Mokelumne River. See the Approach section for more information on CalSim-II limitations.

Table 11. Mokelumne River Flow Effects of Program Scenarios (values shown are annual average changes simulated with CalSim-II; for all years and longest drought sequences in the 82 years of hydrologic record; years 1928 - 1934 and 1986 -1992)

	At Start of Operations	After Ten Years of Operations	After Twenty Years of Operations	When Groundwater is Near Equilibrium
Climate Condition	2030	2030	2030	2070
Period in Program Timeline	Year 0	Year 10	Year 20 (near-equilibrium)	Year 50 (near-equilibrium)
Change in Mokelumne River Long Term (AFY) *(DC-9)*	0	16,980	33,130	30,770
Change in Mokelumne River Drought Periods (AFY) *(DC-9)*	0	12,740	27,640	25,850

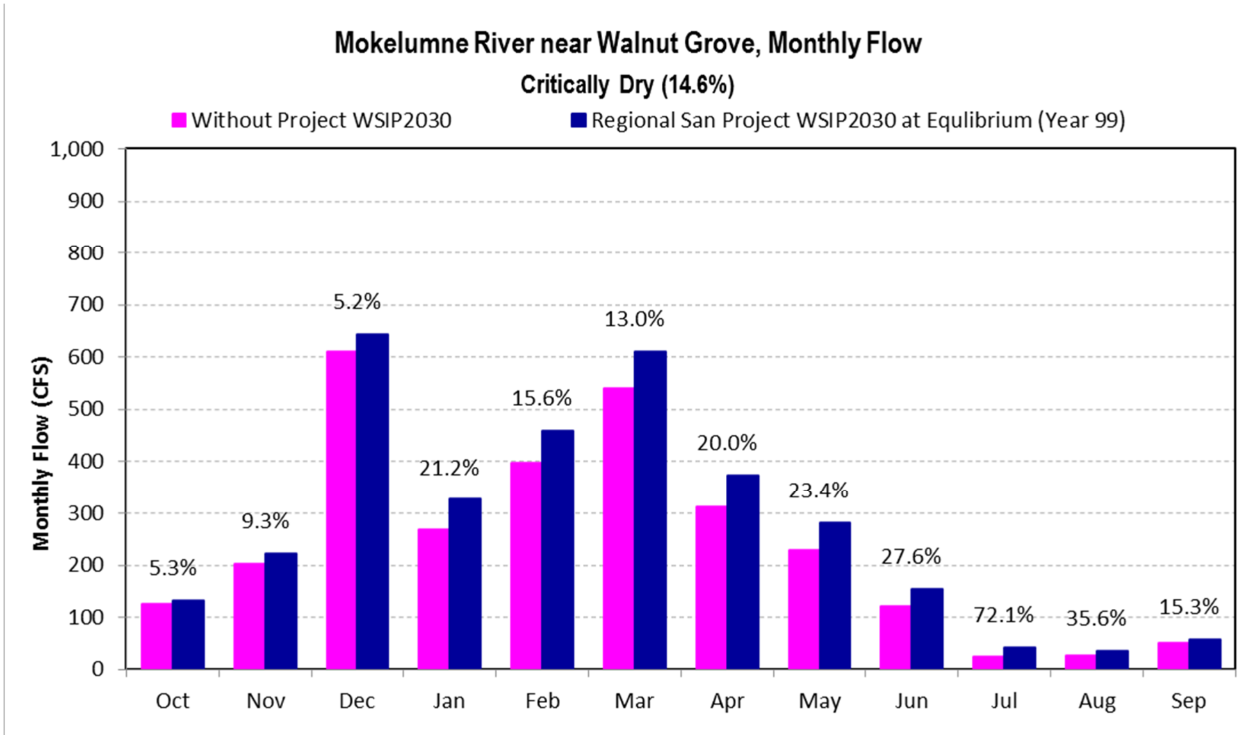

Figure 4. CalSim-II Simulated Results for Flows in the Mokelumne River, With Program after Twenty Years of Operations and Without Program Conditions, Critically Dry Years (D1641 40-30-30).

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